

**Applying Behavioural Science
Techniques to the Test and
Evaluation of Complex Systems**

Noel Sproles

DSTO-GD-0263

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ABSTRACT

The test and evaluation of complex socio-technical systems is difficult. This is especially so when the test and evaluation (T&E) community involved tends to associate itself closely with the physical sciences. The behavioural sciences have developed methods to address such problems and have shown that these methods are capable of providing rigorous results. A discussion of the worth of qualitative data and an overview of the behavioural science methods likely to be appropriate for evaluating complex systems involving humans is provided. A minor case study illustrating the application of qualitative data analysis methods to the evaluation of the Australian Army's Battlefield Command Support System (BCSS) is discussed in order to illustrate the merit of behavioural science methods for T&E.

RELEASE LIMITATION

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AQ 01-06-1128

Published by

*DSTO
Electronics and Surveillance Research Laboratory
PO Box 1500
Salisbury South Australia 5108*

*Telephone (08) 8259 5555
Fax: (08) 8259 6567*

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AR- 011-657
December 2000*

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Executive Summary

This report is adapted from a conference paper submitted for presentation at the November 2000 Systems Engineering and Test & Evaluation Conference (SETE 2000) in Brisbane, Australia. The report points out that while systems engineering (SE) is concerned with problems ranging from the highly abstract to the highly practical, Test and Evaluation (T&E) tends to concentrate on the practical problems. The behavioural sciences offer an opportunity for T&E practitioners to use subjective as well as qualitative data and analysis techniques for the more complex socio-technical systems. The application of such techniques to the evaluation of components of the Australian Army Battlefield Command Support System is discussed as a minor case study. Systems Engineering theory acknowledges the impact and influence that the human element has on the effectiveness of systems. The T&E community needs to acquire the skills to assess this impact. A T&E community with a broader level of expertise will be better able to evaluate new acquisitions of military equipment.

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1. Introduction

There are many definitions of 'system' in the English language but the concept of 'system' used in this report is that expressed in General Systems Theory and reflected in the emerging discipline of systems engineering. A system then is to be considered as a set of components with interrelationships such that they form a unity. They have the properties of emergence, hierarchy, communications, and control (Checkland, 1981).

Jackson and Keys (1984, p. 475) make a distinction between complex and simple systems. They note the small size of the components and the regular interaction between the components for simple systems as opposed to the large number of components and high interrelationships of complex systems. Checkland (1981) describes systems as falling into the four classes of natural, designed, designed abstract, or human activity systems. A term often used, in a similar fashion to Checkland's human activity system, is 'socio-technical systems'. Kline (1995, p. 60) illustrates this when he defines them as linking humans with hardware or tools so as to perform tasks that people want done. Socio-technical or human activity systems generally fall into the category of complex systems, while designed systems are usually considered not to be complex.

The Test and Evaluation (T&E) of designed systems is relatively easier than that of complex systems. With designed systems, there is a structured problem to be solved and it can be taken that the humans involved are united in their views of the nature of the problem and its eventual solution. T&E has traditionally been more involved with designed than with complex systems, with a resulting close association with the various physical sciences such as physics and chemistry, as well as mathematics. This is understandable as the driving force for T&E to date has principally come from industries such as defence and aerospace. Almost always, the goals are clear, are agreed by most if not all those involved, there is an emphasis on physical entities, and there is a total dependence on technology to achieve these goals. T&E has become the domain of the scientist and the engineer who seek quantitative data in order to test and evaluate technological solutions to problems. So long as there is something that can be weighed or whose temperature can be assessed or that can be touched or felt, or such-like, then there is a way of including it in a T&E programme.

Socio-technical or human activity systems problems are generally unstructured and there is more likely to be a plurality of views on the nature of a successful solution. The effectiveness of a public health programme or of a mass transit system will differ dependent on the viewpoint of those concerned. The viewpoint of the commuter using a mass transit system desiring feelings of comfort, service, and security may well differ from that of the politician seeking to allocate funds between several programmes. Often there are no numbers but there is a lot of narrative or words ie., there is little quantitative data but plenty of qualitative data. It would seem that T&E practitioners

are at a loss to develop a T&E programme when faced with such complex system problems as these, because all their experience is with less complex designed systems. This makes it difficult when faced with the T&E of systems in the defence and aerospace areas that should be addressed as complex systems, such as those associated with the Command and Control (C2) of military operations. C2 comprises not only an interaction between pieces of equipment, for example computer hardware and software, but also human beings. The human element is significant and cannot be overlooked. Testing involves such things as how well people communicate and how others understand and interpret communications under extreme stress. Unlike an aeroplane or a truck, test subjects cannot readily be taken into the field and be subjected to repeated tests using a range of likely scenarios over a period of time. Yet, in spite of this, systems such as C2, public sector welfare programmes and organisations need to be tested for effectiveness and performance.

The social sciences deal with both qualitative and quantitative data as a matter of course. Their methods of dealing with the analysis of qualitative data offer means for the handling of the evaluation of complex systems involving human participation. This report will examine the nature of the data used by the social sciences, especially qualitative and subjective data. The distinction between such data and that used by the physical sciences will be discussed as well as the notion that there is no primacy of data between quantitative and qualitative data *per se*. A general overview of the methods used by the social sciences will be presented as will an example of a field where such an approach has already proved successful. Finally, a minor case study where this approach has been attempted for a C2 project will be briefly discussed.

2. The Social Sciences

T&E practitioners are more likely to be familiar with the physical sciences than with the social sciences. The physical sciences are '...the ongoing refined and systematic efforts to understand the inorganic world and the results of those efforts. These are generally divided into four broad areas; physics, chemistry, astronomy, and the earth sciences' (Britannica, 1999). These disciplines deal almost entirely with physical entities, that is items that possess shape, colour, temperature, etc. The term 'Natural Sciences' is sometimes used as well as the term 'physical sciences' to describe '...any of the sciences (such as physics, chemistry, or biology) that deal with matter, energy, and their interrelations and transformations or with objectively measurable phenomena' (Webster, 2000).

The fundamental ideas of the social sciences have their roots with the ancient Greeks and '...their rationalist inquiries into the nature of man, state, and morality' (Britannica, 1999). However, the social sciences in the form of the disciplines by which we know them today came about in the mid-19th century. Modern social sciences deal with the social and cultural aspects of human behaviour and include disciplines such as: anthropology; sociology; psychology; economics; education, and political science.

Law is sometimes mooted as a social science while history is considered to be somewhere on the margin between the social sciences and the humanities. The term 'behavioural sciences' is often applied to the disciplines considered to be social sciences in an attempt to align them with disciplines such as physical anthropology and physiological psychology. Ehrlich (2000, p 2) notes the difference between the social and physical (natural) sciences as being '... modern natural science employs an ontology that is restricted in a particular way: it deals almost exclusively with solely physical things'. As a result of this division, workers in the physical or natural sciences can generally rely on being able to obtain quantitative data. The social or behavioural sciences on the other hand are dealing with human behavioural characteristics such as consciousness and feelings etc. that are not always amenable to quantitative measurement. While quantitative techniques may be useful in some aspects of analysis in the social sciences, such as with language, they are not appropriate where the analysis builds on intuition and on insights gained '...through deep immersion in and dwelling with the data' (Tesch, 1990, p 60). In these instances, the social or behavioural sciences must rely on qualitative techniques for the obtaining and analysis of data.

3. Distinctions Between Data Categories

The distinction between quantitative and qualitative, and subjective and objective data needs to be clarified as the terms are often confused. Subjective data is dependent on the judgement of a human being while objective data is independent of human opinion or judgement. For example, saying that 'It is very hot today' is subjective while saying that 'The thermometer reading today is 41C' is objective even though the observations are both in agreement. Preece et al. (1994, p. 719) provide the generally accepted distinction between qualitative and quantitative when they define quantitative data as '...data that are comprised of numeric values' and qualitative data as data '...that can be categorised in some way but which cannot be reduced to numerical measurements'. Quantitative data deals with numbers but qualitative data deals with meanings that are mediated mainly through language and action. Tesch (1990, p 56) defines qualitative data as words and qualitative research as research using words predominantly or exclusively as data. Dey(1993, p 11) is less restrictive and defines qualitative data as '...virtually any kind of data: sounds, pictures, videos, music, songs, prose, poetry, or whatever'.

Table 1 illustrates the various categories with examples of items from each category. Objective-quantitative data, such as 'airspeed' requires the collection of 'hard' data such as can be measured with some form of apparatus. On the diagonally opposite corner, subjective- qualitative data are very much subject to human opinion eg. 'Can the aircraft be landed on an austere airfield'. There is only one real answer to this: - it can or it cannot.

Table 1: Classification of data (from AFOTECH 99-101,1995).

	<i>Quantitative</i>	<i>Qualitative</i>
Objective	Objective-quantitative <u>Examples:</u> <ul style="list-style-type: none"> • Average airspeed • Maximum detection range. 	Objective-qualitative <u>Example:</u> <ul style="list-style-type: none"> • Demonstrated communications connectivity. EMP/HEMP survivability.
Subjective	Subjective- quantitative <u>Examples:</u> <ul style="list-style-type: none"> • Rating of workload and fatigue. • Average number of crew errors. 	Subjective-qualitative <u>Examples:</u> <ul style="list-style-type: none"> • Test team judgment on capability to land at austere airfield. • Test team judgment on readability of a manual.

4. Value of Qualitative Data

Sometimes the opinion is expressed that quantitative data takes precedence over qualitative data. The sub-title for the paper, from which this report has been adapted, is 'Real men don't collect soft data'. It is from a book of the same name by Gheradi et al. (1987) who were alluding to this notion of one type of data being inferior to the other. Instances of this idea can also be seen in Deming (1982, p. 68) who notes that terms such as round, strong, safe, etc. have no meaning for use in '...business or in government' unless they are able to be defined in statistical terms. Preece et al. (1994, p. 517) when discussing measures (metrics) for software states that 'Once something can be measured numerically, you move away from the world of opinion and intuition'. They quote Lord Kelvin who said in an address to the Institution of Civil Engineers in 1883;

I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind'

Roche et al. (1991, p. 165) dispute this and state that it is a shortsighted view. They argue that '...the most obvious or readily quantifiable measures may not necessarily be the right ones at all' (p. 169). A study of the Combined Bomber Offensive (CBO) against Germany by the British and US Air Forces in WWII was used to illustrate that, at a strategic level, there are '...considerations which go well beyond anything we can quantify' (Roche et al. 1991, p. 184). Dey (1993, p 13) states that 'It would be wrong to assume that quantitative data must take precedence over qualitative data simply because it uses numbers'. He uses the example where body weight may be established quantitatively but where, for a weight watcher, qualitative judgements on whether they are 'thin', 'fat', or 'just right' might be the judgements that count in a social

context. Again, paint may be quantified in terms of lightness, saturation, and hue but the judgement that counts could be the qualitative one of whether it 'clashes' with other colours or is an appealing colour. The quantitative measurements of colour may be meaningful for a paint technologist but qualitative measurements are of more use to the vast majority of the population.

During the formative period of modern social sciences in the 19th century, the success of the physical sciences in this period was noted and the social sciences tried to emulate this success '...through the adoption of quantitative techniques' (Dey, 1993, p.3). There is a heavy emphasis still on quantitative techniques in the social sciences but there is also a growing recognition that qualitative techniques have a significant role. Miles et al. (1994, p. 40) recognises that there is a place for both quantitative and qualitative data when they say '...we have to face the fact that numbers and words are *both* needed if we are to understand the world'. Rossi et al. (1993, p. 437) when discussing the merits of a quantitative as against a qualitative approach, express a similar view. They note that '...each approach has utility, and the choice of approaches depends on the evaluation question at hand'. They stress that the qualitative approach can '...play critical roles in program design and are important means of monitoring programs'. Posavac et al. (1992, p. 211) note how quantitative techniques, while suitable for evaluation when the goals are clear, are not suitable when the goals are vague ie. when different stakeholder groups were able to read their own goals into the objectives of the enterprise. They note the advantage of qualitative techniques when:

- total objective measurement is '...extraordinarily difficult, if not theoretically impossible';
- it cannot be assumed that goals will be clearly stated; and
- programmes are highly sensitive to context or scenario.

That research can be done by talking to people and observing and by trying to make sense of what they observe should really not be surprising to systems engineers. In the world, everything is eventually linked to everything else and from this comes emergent qualities as well as the need to take a holistic view of the world. Instead of arguing for the primacy of one type of data over the other, there seems to be merit in recognising that both types are able to make a contribution.

5. Social Science Methods of Data Analysis

The approaches taken by the social sciences to analyse qualitative data have evolved only in relatively recent times and there is a wide range of names given to the methods used and, for the uninitiated at least, a seemingly incomprehensible associated jargon. Tesch (1990, p 58) lists some 46 different methods in common use which she then breaks up into four 'cognitive maps' that loosely describe the purpose of the research methods. These are:

- the study of the characteristics of language;
- the discovery of regularities;

- seeking to discern meaning; and
- methods based on reflection.

Miles et al. (1994, p. 5) describes Tesch's (1990) taxonomy as one of establishing purpose and proceeds to describe other taxonomies using methods employed to obtain data and even traditions of qualitative research. Dey (1993, p. 5) considers that the plethora of taxonomies used by social scientists is really defensive posturing to either emphasise or even exaggerate '...the subtleties and complexities involved in qualitative analysis'. He points to the need to explain how analytic principles and procedures are applied in social science instead of emphasising how different methods are applied to particular aspects of research. He considers that in all these methods there is a '...common emphasis on how to categorise data and make connections between categories. These tasks constitute the core of qualitative analysis'.

Tesch (1990) shows that one purpose of qualitative research can be to discover regularities and this does have relevance in the evaluation of complex systems such as C2. The cognitive map, shown as Figure 1, demonstrates that this purpose can be further divided into two sub-purposes, of which the one of particular interest for T&E is that of 'discerning of patterns as deficiencies, ideologies'. 'This is shorthand for saying that these types of research are not used for the development of theoretical notions, but for practical scrutiny of human situations, and often also for the formation of alternative solutions where problems are found to exist' (Tesch, 1990, p 65). This ability to undertake 'practical scrutiny of human situations', and the 'formation of alternative solutions' makes qualitative analysis a useful means of undertaking T&E in socio- technical systems. Figure 1 also shows that methods, such as 'action research' or 'qualitative evaluation', may be used to achieve the stated purpose.

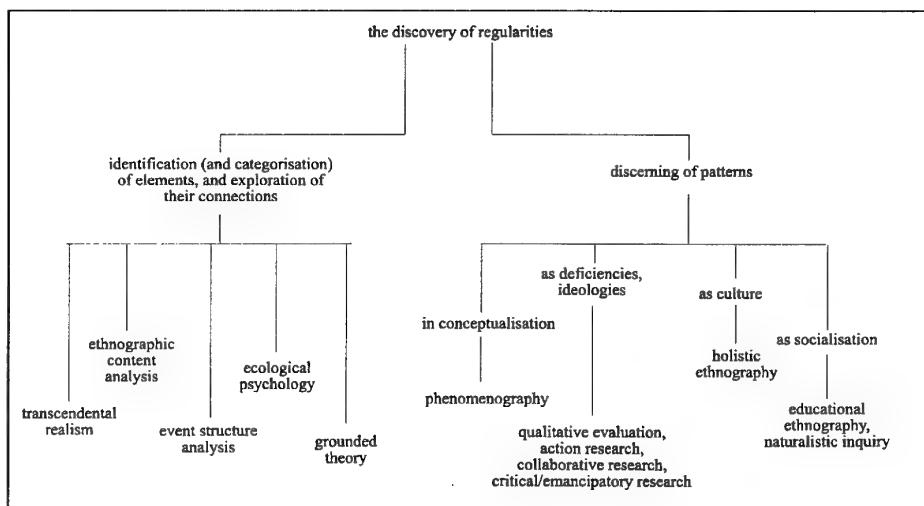


Figure 1: Mapping of qualitative analysis purposes. After Tesch 1990

The methods listed for the purpose of discerning deficiencies have various attributes that make them suitable as methods for the T&E of socio-technical systems where qualitative data either is all that is available or predominates. Brief descriptions of the methods are:

- evaluation research '...seeks to determine whether an action has the results it is meant to have' (Tesch, 1990, p 65) and the most common 'actions' are the programmes implemented by public service agencies using experimental design. This research fits into the concept of establishing T&E programmes based on Measures of Effectiveness (MOE) and Measures of Performance (MOP) (Sproles, 2000a);
- action research is less passive than evaluation research and is geared towards improvement of unsatisfactory situations. It encompasses the human activity systems methodology of Checkland (1981) and can '...be used as a research tool for investigative or pilot research, and generally for diagnosis or evaluation.' (Dick, 1997). As such, it is more appropriate for formative or developmental T&E. Collaborative enquiry and critical/emancipatory research are forms of action research.

6. A Legitimate Approach

The ability to use qualitative methods or approaches to establish regularity indicates that the use of such methods is scientific and legitimate. Wilson(1999) states that 'All science is the search for unity in hidden likenesses. The scientist looks for order in the appearances of nature by exploring such likenesses'. Britannica (1999) puts the case that science is the knowledge of '...natural regularities that is subject to some degree of sceptical rigour and explained by natural causes'. House (1980, p.279) states that 'Naturalistic generalisation employs a special kind of qualitative argument'. Naturalistic can be defined as 'The scientific observation of events as they occur without trying to manipulate them in the form of an experiment in any other way' (Statt, 1993, p.87). House (1980, p. 280) discusses how evaluation based on naturalistic observation is focussed on the understanding of interactions, and searches for explanation rather than prediction.

7. Qualitative Approach in Human Service Programmes

The use of social science methods of qualitative analysis to establish effectiveness has already been successfully applied to human service programmes. These include areas such as the criminal justice system, education, training and safety programmes for industry and business, and in many sections of public administration. There is a body of literature that discusses how these social science methods can be applied to what Posavac et al (1992, p 2) terms 'Programme Evaluation' which is '...a new and exciting applied social science'. While Posavac et al (1992) describes many of the quantitative techniques used in the social sciences, chapter 12 is devoted to the analysis of

qualitative data. In this chapter they acknowledge that evaluation cannot always place an emphasis on experimental control providing quantitative data. They also establish that qualitative research can be rigorous in spite of the element of subjective judgement that it often includes.

8. The Battlefield Command Support System – A Case Study

In early 1999, the Command, Control, Communications, and Intelligence Operations Analysis Group (C3IOA) of the Defence Science and Technology Organisation (DSTO) was asked to evaluate the effectiveness of the Australian Army's Battlefield Command Support System (BCSS). The difficulty in carrying out such a task is the problem of establishing if the C2 system has or has not made a contribution to the accomplishment of the operational mission. Whatever contribution BCSS may make is generally masked by the contribution made by other component systems. Because these contributions are combined to produce an emergent property of the total system, one can rarely be separated from the others. It is only when some gross contribution is made, for better or for worse, that an observer can make such a distinction. It can be shown that the MOEs for systems such as BCSS lie in the contribution that they make to the accomplishment of the military commander's mission (Sproles, 2000b). This is usually very difficult to establish by experiment as the contribution made is generally lost among the synergy that produces the emergent properties of the meta-system represented by the military force itself.

A complication that arose with this study was that there was no opportunity to study BCSS in the field nor was there any opportunity to carry out repetitive testing to establish regularities. Situations such as this are common not only in Australia but overseas (Levi, pers.comm., 1998) necessitating the T&E organisations to seek other means to provide the test and evaluation of systems. In this instance, it proved possible to use methods from the behavioural sciences to accomplish the task.

The approach taken in this case was much along the lines suggested by Dey (1993) in Chapter 3. A snapshot was taken of an Army brigade that had experience in the field with the use of BCSS. The process, as described by Dey (1993), was to collect data, sort it, categorise it, and to make connections enabling a conclusion. The data collection was achieved by interviewing a cross section of members of the formation from the commander down to private soldiers. Interviews were carried out face-to-face with the interviewees at their workplace. The questions were prepared beforehand and were categorised based on existing knowledge of how an effective C2 system was likely to contribute to mission effectiveness. On completion of the interviews the data was entered into Nvivo, a computer based qualitative analysis tool. This permitted the responses to be categorised either into the existing categories or for new categories to be established. At all times, the aim was to funnel data into relevant categories for analysis to enable a conclusion to be made on the contribution of BCSS to mission

effectiveness. In the process, some existing categories were amended in scope, new categories were established, and some categories were allowed to overlap. When this was completed, it was possible to make comparisons between the responses and to make connections between the different pieces of data. A search was made to establish regularities, exceptions to these regularities, and even singularities ie. when comments were made that no one else had made.

It was possible from this to develop a picture of how effective BCSS was at this stage and to draw some conclusions on its future effectiveness. Admittedly this was not a rigorous process due to the limited opportunity and the taking of samples at one point of time only. On the other hand, the data is still available for future use. Given opportunities in the future to carry out a similar exercise, the results can be compared to build up a richer picture. The existing data can be combined with the new data and even re-categorised if so desired. This exercise demonstrated that qualitative techniques were feasible in establishing the effectiveness of a socio-technical system.

9. Conclusion

The use of qualitative data and qualitative analysis is a legitimate tool to establish regularities in a system. In socio-technical systems, such as military C2, they may offer the only feasible means to establish the effectiveness of a system. The techniques used to gather and analyse the data have been developed over a reasonable length of time by social science practitioners and have been shown to be able to produce rigorous results. When such techniques were attempted by DSTO, albeit in a limited way, they produced believable results. There seem to be reasonable grounds to carry out further research in this area to enable these techniques to be adapted for the T&E of socio-technical systems that are proving resistant to T&E by techniques grounded in the physical or natural sciences.

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6a. DSTO NUMBER DSTO-GD-0263		6b. AR NUMBER AR-011-657		6c. TYPE OF REPORT General Document		7. DOCUMENT DATE December 2000			
8. FILE NUMBER N 8316-23-8/1		9. TASK NUMBER DST 00/016		10. TASK SPONSOR CITD		11. NO. OF PAGES 20		12. NO. OF REFERENCES 22	
13. DOWNGRADING/DELIMITING INSTRUCTIONS http://www.dsto.defence.gov.au/corporate/reports/DSTO-GD-0263.pdf				14. RELEASE AUTHORITY Chief, Information Technology Division					
15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT									
<i>Approved for public release</i>									
OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, SALISBURY, SA 5108									
16. DELIBERATE ANNOUNCEMENT									
<i>No limitations</i>									
17. CASUAL ANNOUNCEMENT									
18. DEFTEST DESCRIPTORS									
Complex systems Complex systems Data analysis Qualitative analysis		Test and evaluation Systems engineering Measures of effectiveness							
19. ABSTRACT									
<p>The test and evaluation of complex socio-technical systems is difficult. This is especially so when the test and evaluation (T&E) community involved tends to associate itself closely with the physical sciences. The behavioural sciences have developed methods to address such problems and have shown that these methods are capable of providing rigorous results. A discussion of the worth of qualitative data and an overview of the behavioural science methods likely to be appropriate for evaluating complex systems involving humans is provided. A minor case study illustrating the application of qualitative data analysis methods to the evaluation of the Australian Army's Battlefield Command Support System (BCSS) is discussed in order to illustrate the merit of behavioural science methods for T&E.</p>									